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Improvement of cylindrical deep drawability in hot stamping

Kazuhisa Kusumi^a, Naruhiko Nomura^b, Shuji Yamamoto^a, Masahiro Nakata^b,
Masayuki Abe^a, Masahiro Suehiro^{b*}

^a*Yawata R&D laboratory, Nippon Steel & Sumitomo Metal Corporation, 1-1 Tobihatacho, Tobata-ku, Kitakyushu City, 804-8501, Japan*

^b*Steel Research laboratories, Nippon Steel & Sumitomo Metal Corporation, 20-1 Shintomi, Futtsu City, Chiba, 293-8511, Japan*

Abstract

Deep drawability of steel sheets in hot stamping was investigated. In the case of deep drawing with a conventional die, the forming limit was significantly lower because the temperature of the sheet metal at the flange part decreased during the forming and the flow resistance increased. Therefore, the blank holding method to avoid temperature decrease at flange part of sheet metal was studied. In this study, application of gap supports and forming without blank holder were investigated. In the former method, the gap supports made clearance at the flange part. In the latter method, the blank holder was located at the lower dead point from the beginning of forming and the flange part of the blank was free during forming. The forming limit in both cases was improved as compared with that in the conventional blank holding method. For the application of gap supports, the limiting drawing ratio was also evaluated. In this experiment, the maximum value of limiting drawing ratio was 1.71.

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Keywords: Sheet metal forming; Hot stamping; Deep drawing; Drawability; Forming method; Blank holding

1. Introduction

In recent years, the hot stamping process has been widely adopted for automobile parts production to obtain lighter body weights and better crash safety (Wilsius et al., 2006). We have been studying the basic formability of

* Corresponding author. Tel.: +81-80-8369-4991; fax: +81-93-872-6809.
E-mail address: kusumi.kk5.kazuhisa@jp.nssmc.com

hot steel sheets in hot stamping. Kusumi et al. (2008) investigated the effect of martensitic transformation on spring-back behavior in bending. They found that the excellent shape fixability of hot stamping was caused by not only the low flow stress during stamping but also martensitic transformation. They concluded that the stress introduced by hot stamping was released during martensitic transformation and the elastic recovery was restrained after unloading. Kusumi et al. (2010) also found that the stretch formability in hot stamping strongly depended on the condition of contact between die and sheet. Nakata et al. (2011) clarified that excellent stretch flange formability such as high circumferential elongation of over 120% was obtained in the hole-expansion test in hot stamping.

Regarding deep drawing, Kusumi et al. (2011) have studied draw-bending formability, in which there is no deformation at the flange area, as the first step toward understanding the deep drawability of sheet metal forming in hot stamping. In this report, we studied usual deep drawability with deformation at the flange part in a cylindrical cup drawing. It is thought that the temperature of the sheet metal at the flange part decreases by heat transfer between the sheet and the blank holder during the forming. The temperature decrease at the flange part increases flow resistance and results in making deep drawing difficult. Therefore, avoiding the temperature decrease at the flange part is important for deep drawing in hot stamping. Hence, we investigated the method of blank holding to avoid temperature decrease at flange part of sheet metal to improve the deep drawability in hot stamping.

2. Experimental procedure

2.1. Investigation of the blank holding method

In this experiment, application of gap supports and forming without blank holder were investigated. The tool that is shown in Fig. 1(a) was used; it has large clearance between the punch and the die to prevent damage to the die by the wrinkle. In the former method, the gap supports made clearance at the flange, and the clearance was set to 2.3 and 3.2 mm. In the latter method, the blank holder was located at the lower dead point from the beginning of forming. During forming without blank holder, the sheet metal at the flange part was free. However, when the forming was completed, the sheet metal at the flange part was sandwiched between the die surface and the blank holder. For comparison, the conventional blank holding method and the forming without lower die were also investigated. The schematic diagrams during forming are shown in Fig. 1(b).

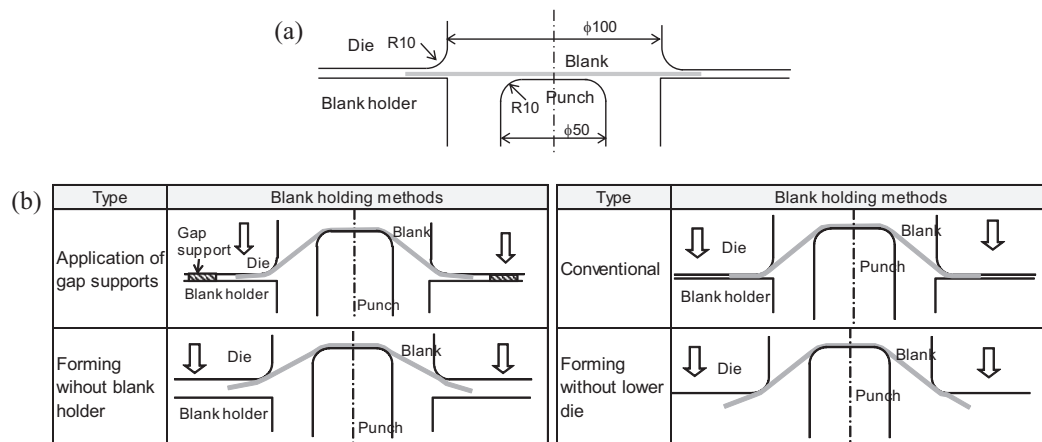


Fig. 1. Tool used for the investigation of the blank holding method: (a) profile of the tool; (b) schematic diagrams of blank holding methods during forming.

Aluminized steel sheets for hot stamping, Usibor[®] 1500P[®], with a thickness of 1.4 mm at a diameter of 150 mm, were used (Wilsius et al., 2006; Suehiro et al., 2003). A steel sheet was heated up to 950 °C, before being transferred onto a die, and then the specimens were held while being formed using hydraulic pressing. The

temperatures at the start of forming were set at 800 °C, the forming speed was 5.7 mm/s, and blank holder forces were fixed at 2.3 tonf. Forming results were evaluated through visual observation of fractures. (*Usibor trademark is property of ArcelorMittal Flat Carbon Europe S. A.)

2.2. Evaluation of drawability in hot stamping by the die with gap supports at the flange part

Drawability is usually evaluated by drawing limiting ratio. To evaluate the drawing limiting ratio in hot stamping, we used the usual cylindrical deep drawing die shown in Fig. 2 that had gap supports at the flange part. The thicknesses of the gap supports were from 1.2 to 2.8 mm. Aluminized steel sheets for hot stamping, Usibor 1500P®, with thicknesses of 1.0, 1.2 and 1.6 mm at diameters of 130 to 170 mm, were used.

A steel sheet was heated up to 1000 °C for the specimen that was 1.6 mm thick, with 1050 °C for the specimen that was 1.0 or 1.2 mm thick, before being transferred onto a die, and then the specimens were held while being formed using hydraulic pressing. The forming start temperature was set at 800 °C, and the forming speed was 13.5 mm/s. Blank holder forces were fixed at 20 tonf, while forming height was set to the height just before finish drawing, for ease in picking up the specimen. In some cases, the lubricant for hot forging was used; the lubricant was sprayed on the die just before forming without drying. Forming results were evaluated through visual observation of fractures. Drawability was expressed by the limiting drawing ratio.

Combined thermal-mechanical coupled simulation corresponding to the present forming tests was also performed using the general structural analysis software “LS-DYNA (Ver. 971)”, in accordance with the method developed by Nomura (2010). Elastic-plastic body shell elements with a mesh of 2 mm for blanks and rigid body shell elements for dies were used, and stress-strain properties were considered depending on temperatures and strain rates based on the actual measurement results.

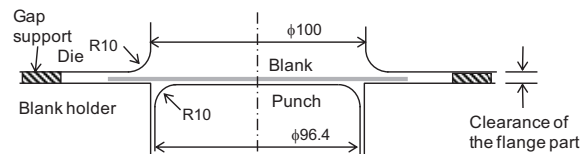


Fig. 2. Tool profile used for evaluation of drawability in hot stamping by the die with gap supports at the flange part.

3. Experimental results and discussions

3.1. Effect of blank holding methods on formability in hot stamping

The forming results shown in Fig. 3 are mentioned below. The appearance of the formed specimens at forming height of 30 mm is also shown in Fig. 4.

- (1) Conventional blank holding: A necking occurred at forming height of 25 mm, and a fracture occurred at forming height of 30 mm.
- (2) Application of the gap supports: A fracture occurred at forming height of 32 mm in the case of 2.2-mm-thick gap supports, and a fracture occurred at forming height of 35 mm in the case of 3.4-mm-thick gap supports. In comparison with conventional blank holding, the formability was improved; thicker gap supports were effective in improving the formability. It was thought that the temperature decrease at the flange part of the sheet metal was suppressed by this method.
- (3) Forming without blank holder: A fracture occurred at forming height of 35 mm. The formability was improved in comparison with the conventional blank holding method. It was thought that the temperature decrease at the flange part of the sheet metal was also suppressed because the flange part of the blank was free. Some powering of the coating layer was observed at the flange part of the forming specimen. It suggested that wrinkles occurred during forming, and these were completely flat after forming. The wrinkles that occurred during forming completely disappeared when the blank was sandwiched between the blank holder and the die surface by applied pressure. It was thought that the stress introduced by flattening of the wrinkles was relaxed by martensitic transformation, same as the improvement of the spring-back in hot stamping (Kusumi et al., 2008).

(4) Forming without lower die: Buckling occurred at forming height of 30 mm.

According to the above results, application of the gap supports and forming without blank holder were effective in improving the formability. The reason was thought that these methods suppressed temperature decrease at the flange part of the sheet metal.

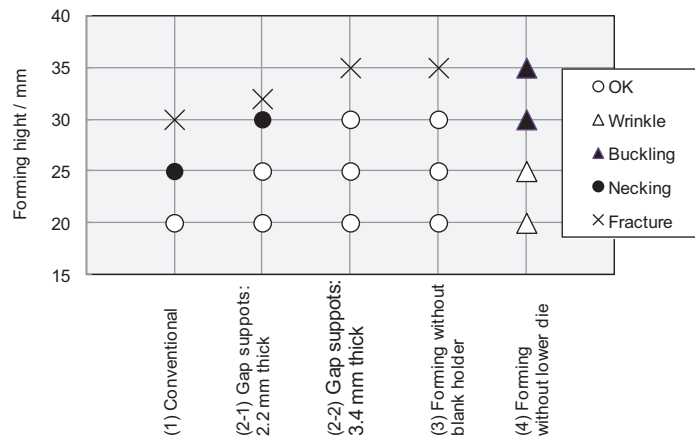


Fig. 3. Effect of blank holding methods on the forming results.

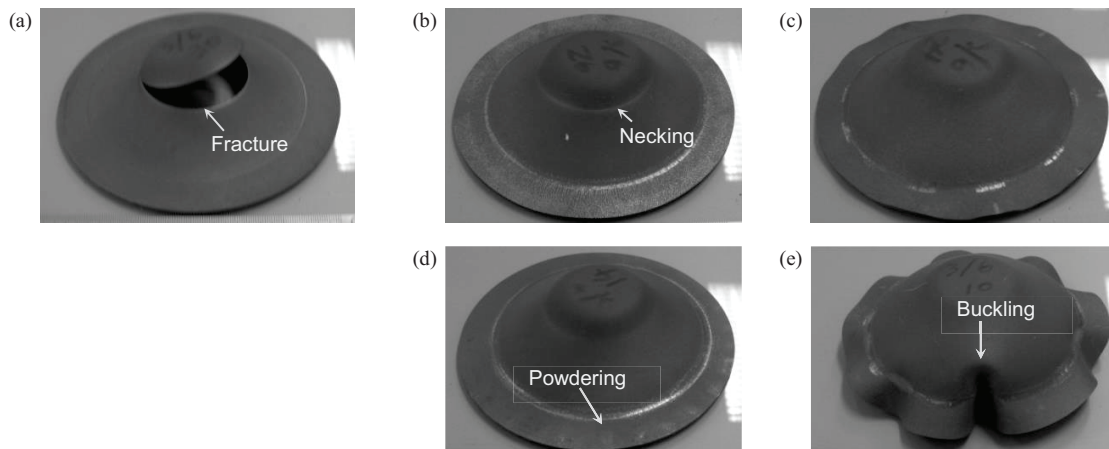


Fig. 4. Appearance of forming specimen at forming height of 30 mm: (a) conventional blank holding; (b) 2.2-mm-thick gap supports; (c) 3.4-mm-thick gap supports; (d) forming without blank holder; (f) forming without lower die.

3.2. Effects of clearance of the flange, thickness of the blank, and lubrication on the limiting drawing ratio

Fig. 5 shows the effect of the clearance of the flange on the limiting drawing ratio. From this result, when the clearance of the flange was larger, the limiting drawing ratio increased in every case. In this experiment, the maximum limiting drawing ratio that we could succeed in obtaining was 1.71 in the case with a sheet thickness of 1.6 mm, with a clearance of the flange at 2.8 mm, and with lubrication for hot forging. We also found that the lubricant for hot forging was effective in improving the limiting drawing ratio in this experiment. Fig. 6 shows the appearance of drawing cups in this experiment. We can see that the wrinkle that occurred at the flange part tends to remain when the clearance of the flange was larger. Fig. 7 shows the effect of sheet thickness on the limiting drawing ratio in the case when the clearance of the flange was 2.8 mm. From this result, we can see that the larger thickness improved drawability in the hot stamping process.

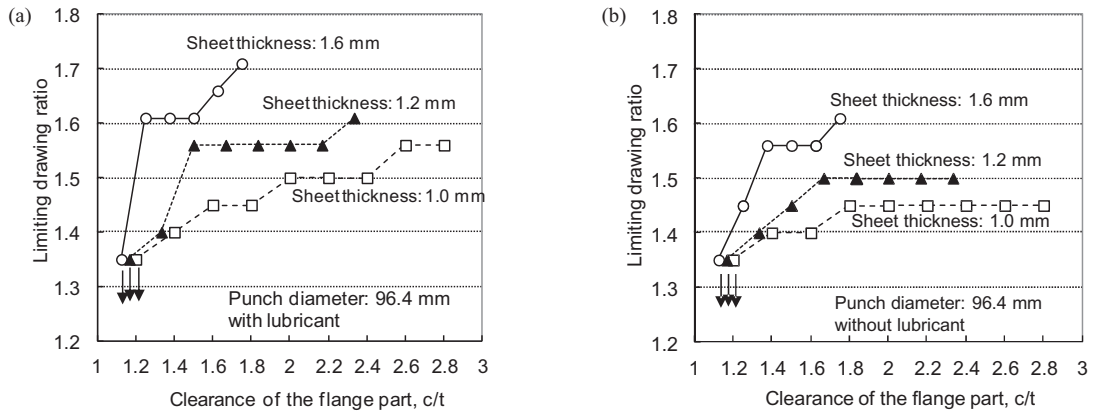


Fig. 5. Effect of clearance of flange part of die on limiting drawing ratio: (a) results with the lubricant case, (b) results without the lubricant case.

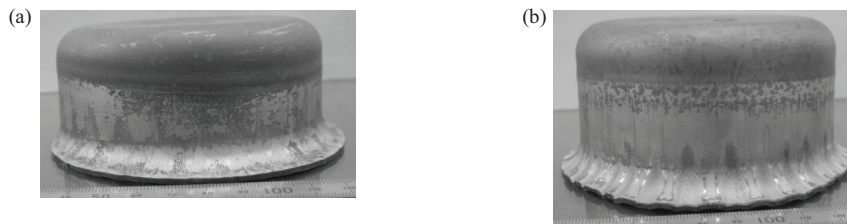


Fig. 6. Appearance of drawing cups: (a) drawing ratio: 1.61, clearance of the flange: 2.4 mm, with lubricant; (b) drawing ratio: 1.71, clearance of the flange: 2.8 mm, with lubricant.

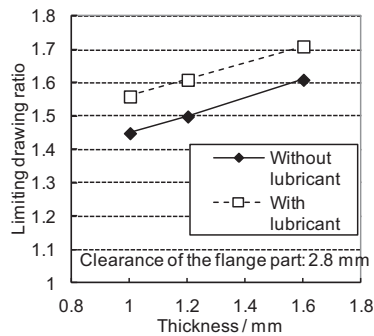


Fig. 7. Effect of sheet thickness on limiting drawing ratio in case when the clearance of the flange was 2.8 mm thick.

Fig. 8(a) shows the effect of clearance of the flange and sheet thickness on the forming analysis results of the distribution of equivalent stress and temperature during deep drawing at forming height of 30 mm. It was proven that the equivalent stress was smaller when the clearance of the flange was larger. This seems to be because the deformation resistance decreased for the higher temperatures of the flange part. It was also proven that the equivalent stress was larger and that the temperature of the side wall was lower when the sheet thickness was smaller. The reason for this seems to be that the temperature was easy to decrease because the thickness was small, and this makes the deformation resistance in bending deformation at the die shoulder larger.

Fig. 8(b) shows the effect of the friction coefficient on the analysis results of the distribution of equivalent stress and temperature during deep drawing at forming height of 30 mm. This analysis was performed to consider the effect of the lubricant. There was no friction coefficient for this lubricant in the hot stamping process. Therefore,

the friction coefficient for the lubricant was assumed as 0.3 in this analysis. As a result, there was no large difference in temperature distribution. However, the equivalent stress was larger when the friction coefficient was larger. According to this result, the decrease in friction through lubrication seems to be effective in improving deep drawability in the hot stamping process.

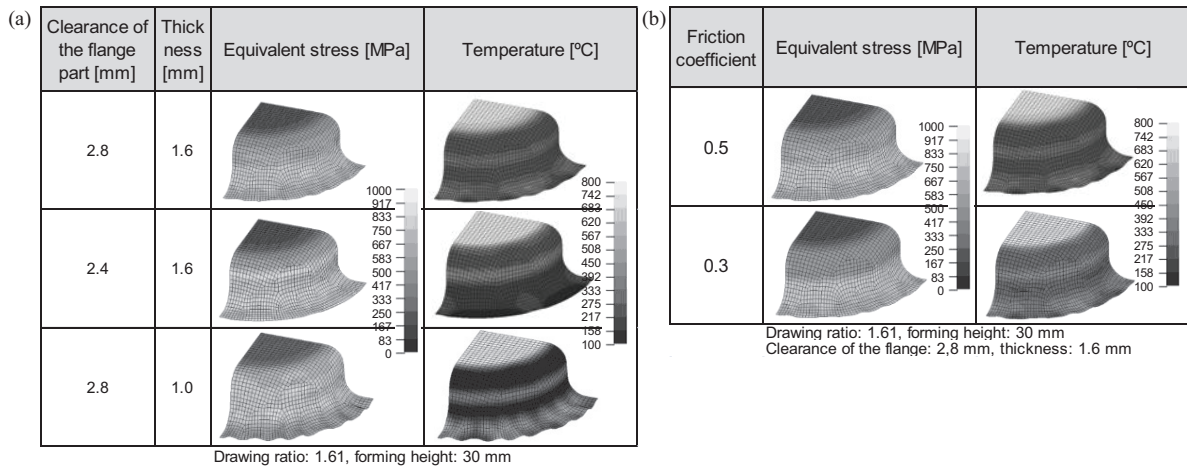


Fig. 8. Results of forming analysis at forming height of 30 mm: (a) effect of the clearance of flange part and sheet thickness on equivalent stress and temperature of the blank, (b) effect of friction coefficient on equivalent stress and temperature of the blank.

4. Conclusion

We investigated the effective method to improve drawability in hot stamping. It was shown that application of gap supports at the flange part of die and forming without blank holder were effective in improving deep drawability. It was thought that these methods suppressed the temperature decrease at the flange part of the sheet metal.

In the case using gap supports at the flange part of the die, the limiting drawing ratio depended on the clearance of the flange part; a larger clearance improved the deep drawability in hot stamping. In this experiment, the maximum value of the limiting drawing ratio was 1.71. The limiting drawing ratio also depended on the sheet thickness; when the sheet thickness was larger, the limiting drawing ratio also became larger. Lubrication was effective in improving deep drawability in hot stamping.

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